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Design and Development of a Conductive Rotating Drum Type Solar Dryer

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Abstract*— The present investigation was oriented toward establishing the foundations for the design of a conductive rotating drum-type solar grain dryer for the fulfillment of the proposed objective. Among the principal findings, it was clear that the design parameters for a conductive rotating drum-type solar grain drier could be established thanks to the theoretical and methodological underpinnings that were suggested. Green peas and recently harvested maize were used to test the system. The results obtained indicate that 128 kg of grains could be successfully dried utilizing conductive spinning in the presence of favorable weather. A cylindrical drum of 1.125 meters in length and 0.330 meters in diameter rotate at a speed of 10 revolutions per minute (rpm) in this setup. The main goal of this design is to improve grain mass, increase surface exposure, and even dry the grain as a result of the drum's rotation. Within the dryer's drying cabinet, an average drying temperature of 53.4°C was noted. The average temperature differential between the interior of the drum cabinet and the surrounding air was 15.2 ºC, which proved adequate to dry maize and green peas grain efficiently for high-quality grain. The proposed drying system is functional as evidenced by the total thermal energy to be created inside it, which is 7.42 KWhr per day at a drying rate of 2.075 kg/hr with moisture removed 83% from maize grains and 2.12 kg/hr with moisture removed 85% from green peas, respectively. The current study demonstrates that even low-cost solar drying devices can be highly effective at producing the necessary amounts of heat needed to dry grain. The suggested design comes in at 35000/-Rs, which is the lowest cost of comparable facilities for the drying application available in the market.

***Index Terms*— Conductive, Drying Rate, Grain Drying, Rotating Solar Dryer, Moisture**

I. INTRODUCTION

Solar drying has a long history. It traditionally began with drying by the sun, better known as sun-drying. In this method, the product is exposed directly to sun rays, allowing it to be dried by radiation from the sun. However, this method has disadvantages, such as exposure of products to wind, rain, moisture, dust, animals, insects, and fungus growth. This process is also time-consuming and requires a large area. From the concept of solar drying, solar dryers came up. The basic principle of a solar dryer is to pass hot, dry air heated by solar energy over products to be dried. Solar drying has been revealed to be a cost-effective and efficient alternative to traditional and mechanical drying systems, especially in areas of good sunshine like India.

Various types of solar dryers have been designed to improve solar drying capabilities, such as solar greenhouse dryers, solar cabinet dryers, forced convection dryers, and many others. However, one major problem that exists with these solar dryers is their capability to dry products only with the existence of solar energy, enabling them to be operated only on hot days. This causes inconsistency in drying and a decrease in the production scale. This research incorporates the use of the direct conductive solar dryer to precisely control the speed of the drum's rotation. This allows you to optimize the drying process by adjusting the drum's speed based on factors such as the type of grain, moisture content, and ambient conditions.

Food spoilage is a major problem. Causes of spoilage include the growth of microorganisms such as yeasts, molds, and bacteria. The presence of water is a key factor in all these processes. Microorganisms need water to support their lives. Very few chemical reactions can occur without the presence of water. The dissolved sugars serve as a source of nutrients for microorganisms. This creates an ideal environment for microbial growth and chemical reactions. The removal of water basically shuts down the growth of microorganisms and prevents chemical reactions from taking place. The important thing to note is that there is an incredible amount of water we eat. In order to prolong the storage life of foods, water has to be removed. [14]

II. LITERATURE REVIEW

2.1. Adhered M. Tayeb and colleagues (1985) investigated and were concerned with current solar grain dryers. A rotary dryer is made up of a revolving cylindrical shell that is slightly tilted towards the outlet.Wet feed enters one end of the cylinder and dry material exits the other. Internal flights raise the solids and shower them down through the interior of the shell as the shell rotates. The shell is 1.5 mm thick galvanized iron that is soldered to a 6-mm iron face at either end. The two faces are performed to ease air entry and departure from the cylinder. Two nuts secure the faces to the shaft. One face has a small suction fan to aid in the flow of hot air through the grains to be dried. The cylinder is 1 m length and 0.28 m in diameter. To maximize the absorbed energy of the solar radiation, the cylinder is coated with a thin film of a specific black paint. As a result, the cylinder serves as both a drier and a solar collector. By the action of the suction fan, air enters from one perforated end, is heated by contact with the black metallic shell, causing the grains in the shell to dry, and ultimately exits from the other perforated end. The used motor has a primary speed of 1440 revs per minute. This was lowered to a manageable number of rotations in two steps by combining two gears (worm and helical gears) and two pulleys of varying diameters.The rotary drier was successfully used to dry free-flowing grains. Drying samples of corn and peanuts were used to assess performance. Throughout June 1982, tests were conducted. To calculate the drying rate, we assumed the drying area was 20% of the overall area of the shell.[3]

As a result, the drying area = dl x 20/100 = 460 cm^2.

(i) Using a solar rotary drier, solar energy was efficiently used to dry corn and peanuts with initial moisture contents of 54.3% and 22% to 6.5% and 10% in 5.30 hours and 3 hours, respectively.

(ii) The current study reveals that even simple solar drying devices can be extremely efficient for the requisite levels of heat needed to dry grain.

2.2. Design, construction, and performance evaluation of a paddy rice solar drum dryer equipped with a perforated drum were investigated by Maedeh Leilayi, Akbar Arabhosseini, Mohammad Hossein Kianmehr, and Heman Amiri (2023). Rice drying, a solar drum drier with a fixed outer drum and an inner perforated drum that revolved at the necessary rotational speed inside the outer drum was devised and built. The dryer's maximum capacity was 10,000 g. The inner drum's rotating speed was controlled. A solar absorber plate produced the thermal energy necessary by the dryer. The performance of the dryer was evaluated at three different rotational speeds (0.21, 0.42, and 0.84 rpm), drum slope (1°, 1.5°, and 2°), and air velocity (1.7, 1.8, and 1.9 m/s). The diameter of the drum was the geometrical parameter that affected the movement of the particles, and the ratio of the particle diameter to the drum diameter changed with the change in the drum diameter. Therefore, increasing the diameter of the drum caused a reduction in the repose angle of the paddy without any effect on the filling angle. The displacement of the product along the drum grew as the slope and rotational speed increased. The time necessary to remove moisture (13%) was smaller at the lowest air velocity. The results revealed a considerable reduction in cracked brown rice for paddy dried by drum dryer at 43-46°C compared to batch dryer. The paddy with the greatest stress-cracking index (11) had an initial moisture content of 16%. According to the findings, a longer drum should be considered for proportional ultimate moisture content to intensify the slope and rotational speed of the inner drum.[6]

III. DESIGN APPROACH AND METHODOLOGY

3.1. Fundamentals of the Grain Drying Process:

The three primary divisions of grains are cereals, legumes, and oil seeds. They rank among the most vital staple foods in the world, constituting a sizeable amount of both human nutrition (34.4%) and animal feed (65%). Grains are important sources of vitamins, minerals, fibers, crude fat, proteins, essential fatty acids, carbs, and inorganic elements, all of which are important for human health. Drying is the most widely used preservation method and the most diversified unit activity in agricultural grain. The drying process significantly affects the quality of dried grains. It plays a vital role and has a significant impact on the performance of milling and grinding operations. The drying process includes a combination of heat, moisture, and momentum interactions in which the moisture in the grain is decreased to a desirable level (e.g., 8.5 to 13.0% for rice, 8.0–13.5% for corn, 8.0–15% for beans, and 4.5 to 7% for peanuts). Several drying methods and different processing conditions, such as heat intensity, air velocity, drying duration, and the initial condition, could significantly affect the quality of the final dried products, such as high moisture, cracks, burnt grains, etc.

3.1.1. Moisture and phase change:

Moisture and its phase shift are found in a variety of engineering and biotechnological applications where heat and mass exchange are inextricably linked. In the drying phenomenon, the water is evaporated from a product and the water vapour is removed from the dryer at the same time. Similar to grain moisture removal, partial evaporation of the liquid phase occurs inside the substrate and the exposed surface. The liquid is transformed into a vapour phase that is evacuated from the substrate. Removal of the reduced moisture level facilitates postharvest handling and avoids microbiological deterioration; hence, it improves the nutrient retention and economic value of the grain.

The primary characteristic that guides the drying of agricultural grains is the combination of heat transfer (environment to grain) and moisture migration (grains to the environment). The temperature, relative humidity, velocity, moisture, and solid elements of the grain determine the heat and mass transfer during grain drying. The physicochemical properties such as texture, size, minerals, and proximate composition of the grain have a huge impact on the drying kinetics of the material.[16]

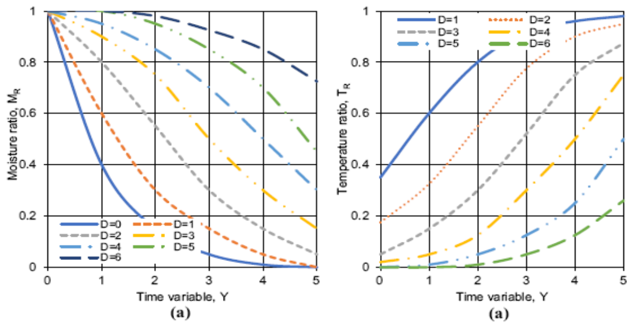

Fig.3.1. Moisture ratio-time ((a) and temperature–time; (b) relationship pattern for the grain drying process; D = different dryer layers)

The moisture loss of the grains during the drying process is sensitive to the number of grain layers subjected to the drying process and quantifies the process by the moisture ratio profile of the dried grain under different layers (D). The path of moisture migration is shown in Fig.3.1. (a) and the corresponding temperature profile of the grain during the drying process is illustrated in Fig. 3.1.(b)

3.1.2. Mass Transfer:

The moisture inside biological products can be classified as vacuolar, cytoplasmic, extracellular, and others. The transformation between different moisture types has been defined as a function of changes in cell structure during drying by considering the variation in mass because of moisture migration. The moisture has been further classified into four categories: highly mixed water, combined water, free water, and others. Due to its comprehensive theoretical foundation, this categorization approach is currently frequently employed. Although the influence of this moisture class is not addressed during. The drying process, mass transfer regulates the transition of this within the several moisture-binding kinds in the grain and the surroundings. During the drying process of grain, the air-grain mass transfer is described by a mass kinetic equation.[16] The reduction of the grain moisture content to a safe storage level involves mass transfer processes, whose kinetics are defined in several studies based on the mass of the grain before and after drying. The magnitude of the transfer phenomenon of grain drying is quantified based on the instantaneous moisture content (time-dependent moisture content), moisture ratio, drying rate, and equilibrium moisture content, which are determined from Equations 1-4.

$$MC_{wb} = \frac{W_w - W_d}{W_w}\ ;\ MC_{db} = \frac{W_w - W_d}{W_{wd}} \qquad (1)$$

Where MC_{wb} and MC_{db} are the moisture content on a wet and dry basis (%) respectively, W_w is the grain wet mass (g) and W_d is the grain dry mass (g).

$$MR = \frac{M_g - M_e}{M_o - M_e} \qquad (2)$$

Where MR is the moisture ratio, M_g is the grain moisture at a specific time (%), M_e is the equilibrium moisture content (%) and $M_o$is the initial moisture content (%).

$$DR = \frac{dm}{dt} = \frac{M_g - M_o}{t_g - t_o} \qquad (3)$$

Where DR is the drying rate (%/s), M_g is the grain moisture at a specific time (%), M_o is the initial moisture content (%), t_g is the specific drying time (s) and t_o is initial drying time (s).

$$M_e = \frac{a + bT}{(100\ RH - 1)^{1/c}} \qquad (4)$$

Where M_e is the equilibrium moisture content (%), T is the temperature (K), RH is the relative humidity and a, b and c are the constant parameter.

3.1.3. Heat transfer:

The temperature difference between the grain and the immediate surroundings is used to study heat transmission during grain drying. They act as a driving force that monitors heat transfer from a hot (heating) situation to a cooler zone (grain). The modes of heat transmission during grain drying include conduction, convection, and radiation.

Heat transfer is a process in which heat energy is transferred from one medium to another medium due to a temperature difference. Heat transfer is the exchange of thermal energy between physical systems. The rate of heat transfer is dependent on the temperatures of the systems and the properties of the intervening medium through which the heat is transferred.

The term "solar drying" refers to a process that transforms incident solar radiation into the thermal energy needed for drying. The majority of solar dryers employ solar air heaters, which then send hot air through the drying chamber, which contains the material to be dried. The substance loses moisture as a result of the air's energy transfer to it. Heat is required to remove moisture from the material during drying, and air movement aids in removing the moisture. The movement of moisture from a material's interior to its surface and the evaporation of moisture from the surface into the surrounding air are the two fundamental mechanisms involved in the drying process.

Parameters involved in the drying process:

• Heat transfer • Drying atmosphere • External conditions
• Type of grain • Air temperature • Air speed
• Moisture content of the grain • Amount of grain to dry

In reference to the type of grain to be dried, it is very important to know:

• Moisture content present in the grain to be dried.
• Maximum drying temperature that the product can withstand without losing its properties.
• Specific volume, density and porosity of the grain.
• Percent of extraction of grain moisture per hour without losing its physical, chemical, nutritional and quality

properties. [8]

3.2. Temperature:

The minimum temperature for drying food is 30 °C, and the maximum temperature is 65 °C; therefore, 50°C and above is considered average and normal for drying grains, vegetables, fruits, roots, crop seeds, and some other crops.

3.3. Air Velocity:

The main functions of the air speed inside the dryer are to transmit the energy required to heat the water contained in the grain, facilitate its evaporation, and transport the moisture evaporated by the material. The air speed for the correct drying of the grains in the rotary dryers must be between 0.25 to 2.5 m/s.

3.4. Moisture Content of the Grain:

During the drying process, it is necessary to know and define some terms that allow expressing the amount of water contained in the grain to be dried as well as the amount of water that must be removed. The following expression is used to calculate them:

The moisture content are calculating as a percentage of the final dried mass of the grains and the difference between the initial mass of the grains.[12]

Moisture Content removed (%) =

$$\frac{\text{Initial Weight of Grain} - \text{Final Weight of Grain}}{\text{Initial Weight of Grain}} \text{ x } 100\ \%$$

3.5. Rate of drying:

Drying rate is well-defined as the quantity of moisture removed divided by time (Dhanushkodi et al., 2014).

$$\text{Drying Rate} = \frac{W_i - W_d}{t}$$

Where, W_i = Initial weight of the sample, g or Kg
W_d = Weight after drying, g or Kg
t = Time of drying, hours

3.6. Effect of rotation on moisture removal in grain solar drying:

The rotation of the drum promotes better airflow within the grain mass. As the drum rotates, the grains tumble and mix, allowing the heated air to penetrate deeper into the grain bed. This improved airflow ensures that moisture-laden air is continuously replaced with drier air, leading to more efficient moisture removal. As the grains move, different surfaces come into contact with the heated air, allowing moisture to evaporate from a larger surface area. This increased surface exposure accelerates the drying process. It also helps to achieve more uniform drying throughout the grain mass. During the drying process, grains tend to stick together and form clumps due to moisture content. The rotation of the drum helps to break up these clumps, ensuring that individual grains are exposed to the drying air. This prevents localized areas of high moisture content and facilitates uniform drying.

3.7. Maize and Green Peas Grains for Experimentation:

Maize and green peas are widely cultivated crops in the Sangli area, making them readily available for experimentation. Maize and green peas contain a significant amount of moisture, which makes them suitable for studying the effectiveness of solar drying methods. It can change color during the drying process, which makes it useful for assessing the impact of solar drying on the visual quality of food products. Maize and green peas are staple food crops in many regions, so understanding their drying characteristics is crucial for good security and post-harvest management. Maize is chosen as a representative grain for drying studies because it shares similarities with other grains, making findings applicable to a broader range of crops. Researchers often use maize to study drying rates, which can vary based on factors like temperature, humidity, and solar exposure. This information is valuable for optimizing drying processes in agriculture and food preservation.

IV. DESIGN OF CONDUCTIVE RORATING DRUM TYPE SOLAR DRYER

4.1. Design of the rotary drum dryer.

The sizing of a drying installation is based on the production parameter and the product to be dried. The importance of each of them depends on the product to be dried.

Thickness of drum sheet= 2 mm
Radius of drum =330mm
Length of drum = 1125mm
Weight of drum and shaft = 80 kg
Weight of grain in drum = 120 kg
Total weight of drum, shaft and grains in drum /load = 200 kg
Drum rotate at a speed of 10 rpm

4.2. Theoretical bases for calculating the power required to move the rotary drum of the drying installation.

The element of the reduction system that generates the power necessary to move the rotary drum is the electric motor. The other elements of the speed reduction system, such as sprockets and chain are responsible for transmitting this power to the drive shaft that drives the rotary drum.

The tangential and radial forces acting on the rotating drum.

The total tangential force or load acting on the system.

Tangential Force = Tangential Load due to entire weigh t + Centrifugal force acting due 120 kg of grains.

Tangential Load (m) = 200 kg x 9.81 m/s²
= 1992 kgm/s²= 1992 N

Centrifugal Force (F)= Mass of grains (m) x radius(r) x angular velocity ²(ω)

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Angular Velocity (ω) –

$$RPM= \omega \times \frac{60}{2\pi}$$

$$\omega= \frac{10 x 2\pi}{60}= 1.047 \text{ rad/s}$$

Radius of Drum (r)= 0.330 m
Centrifugal Force = 120 x 0.330 x 1.047^2 = 43.5N
So total tangential load acting on the system = 1992+43.5
= 2035 N

The radial force acting on the drum and shaft can be calculated by considering the net force in the radial direction.

Angular Torque (T) = Radial Force (F) x Radius of Drum(r)

Angular acceleration (α or A) =

$$\alpha = \frac{\text{Final angular velocity} - \text{Initial angular velocity}}{\text{Time required for velocity change(change in time)}} = \frac{\omega_f - \omega_i}{\Delta t} = \frac{1.047 - 0}{6} = 0.174 \text{ rad/s}^2$$

The dryer consist of 4 drying cabinets, each drying cabinet have 30 kg capacity to hold the grains.

Angular Torque (T) = m.A.r
=(30 x 9.81) x 0.174 x 0.330
= 16.898 N.m

$$\text{Radial Force (F)}= \frac{\text{Angular Torque (T)}}{\text{Radius of Drum (r)}}$$

$$F= \frac{T}{r} = \frac{16.898}{0.330} = 51.20 \text{ N}$$

So total radial Force acting on the 4 cabinets of drum and shaft = 4 x 51.20 = 204.82 N

Total tangential and radial force acting on the rotating drum dryer = 2035+ 204.82 = 2240N ≈ 2240 N

Total torque transmitted by the shaft:

Torque required (T) = Total Force (F) X Radius of drum (r)
= 2240 x 0. 330
= 7392000 N.mm = 740 N.m

4.3. Theoretical bases for calculating the power required to move the rotary cylinder of the drying installation.

The torque transmitted 740N.m and drum rotated at a speed of 10 RPM the Power required to drive the drum

Power (P) = Torque transmitted (T) x Angular Velocity (ω)

$$P= \frac{2\pi NT}{60} = \frac{2\pi \times 10 \times 740}{60} = 774.53 \text{ watt}$$

4.4. Design of rotating shaft

Material used for shaft is Mild steel structural ASTM A36 steel.

Ultimate Tensile strength – 400MPa (N/mm²)

Shear strength (τ) – 200 MPa (N/mm²)

When the shaft is subjected to a twisting moment or torque, the diameter of the shaft may be obtained by using the torsion equation. We know that

$$T = \frac{\pi}{16} \times \tau \times d^3$$

$$d^3 = \frac{T \times 16}{\pi \times \tau} = \frac{726000 \times 16}{\pi \times 200}, \ d = 26.44 \approx 30 \text{ mm}$$

We select the standard size of shaft having diameter 30 mm.

If a shaft with a diameter of 30mm can sustain a specific load in the bending moment, The shafts ability to withstand bending moments if the total tangential load acting on the shaft is 1992 N.

Bending moment at centre C

M_C = 981 x 655
= 642555N.mm

When the shaft is subjected to a bending moment, then the maximum stress (tensile or compressive) is given by the bending equation. We know that

$$\frac{M_C}{I} = \frac{\sigma_b}{y}$$

$$\text{Bending stress induced in the shaft} = \sigma_b = \frac{M_C}{\frac{\pi}{64} \times d^4} \times \frac{d}{2}$$

= 242.40 N/mm²

Yield strength for mild steel ASTM A36 steel material 250 MPa (N/mm²)

σ_b = 242.40 MPa (N/mm²) < Yield strength (250 MPa (N/mm²)

4.5. Bases for the design of a grain drying installation:

Average solar energy receiving in India 5-7 KWhr/m²
Length of the drum = 1125 mm
Diameter of the drum = 660 mm
Number of Cabinets =4
Number of absorber plate =4
Surface Area of single absorber plate = 1125mm x 330mm
Area subjected to solar radiation of single absorber plate
= 0.330 x 1.125 = 0.371 m²
Total area subjected to solar radiation
= Area of Single cabinet x No. of Cabinet
= 0.371 x4 = 1.484 m²
Average solar energy receiving in India 5-7 KWhr/m²
Energy received by single cabinet in a day = 5 x 0.371
= 1.855 KWhr per day
Total energy received by the all four cabinets = 5 x 1.484
= 7.42 KWhr per day

The window period for drying of grains is 8 hours then energy received in per hour 1.855 / 8 = 0.231 KWhr

Heat is absorbed by grains inside the drum cabinet Q_A

$$Q_A = 0.231 \times 3600 \text{ KJ} = 831.6 \text{ KJ}$$

To estimate the maximum amount of mass that can be dried with a temperature difference of 15°C, we can use the heat transfer equation.

$$Q_A = m \times C_P \times \Delta T$$

Where Q_A = Heat Absorbed by the grains in kJ.

m = mass of the grains in kg.

ΔT= temperature difference between the atmospheric temperature and temperature inside the cabinet in °C,

C_P = Specific heat of maize or corn 1.4868 to 2.4242 KJ/Kg °C ≈ 1.7 KJ/Kg °C

Assuming that the specific heat capacity of the maize and the temperature difference (ΔT) is 15°C

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Atmospheric average temperature =38°C

Average temperature inside the dryer cabinet - 53°C

$$Q_A, = \text{m x } C_P \text{ x } \Delta T$$

831.6 = m x 1.7 x (53-38)

m = 32 kg

32 kg of grain can be dried in one cabinet of the drum with a temperature difference of 15 ºC. So a total of 128 kg of material can be dried in a drum at a time.

4.6 Proposed CATIA model of conductive rotating drum type solar dryer

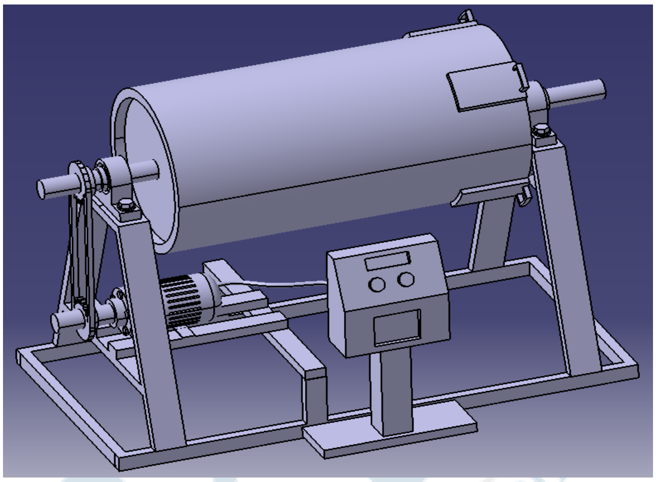
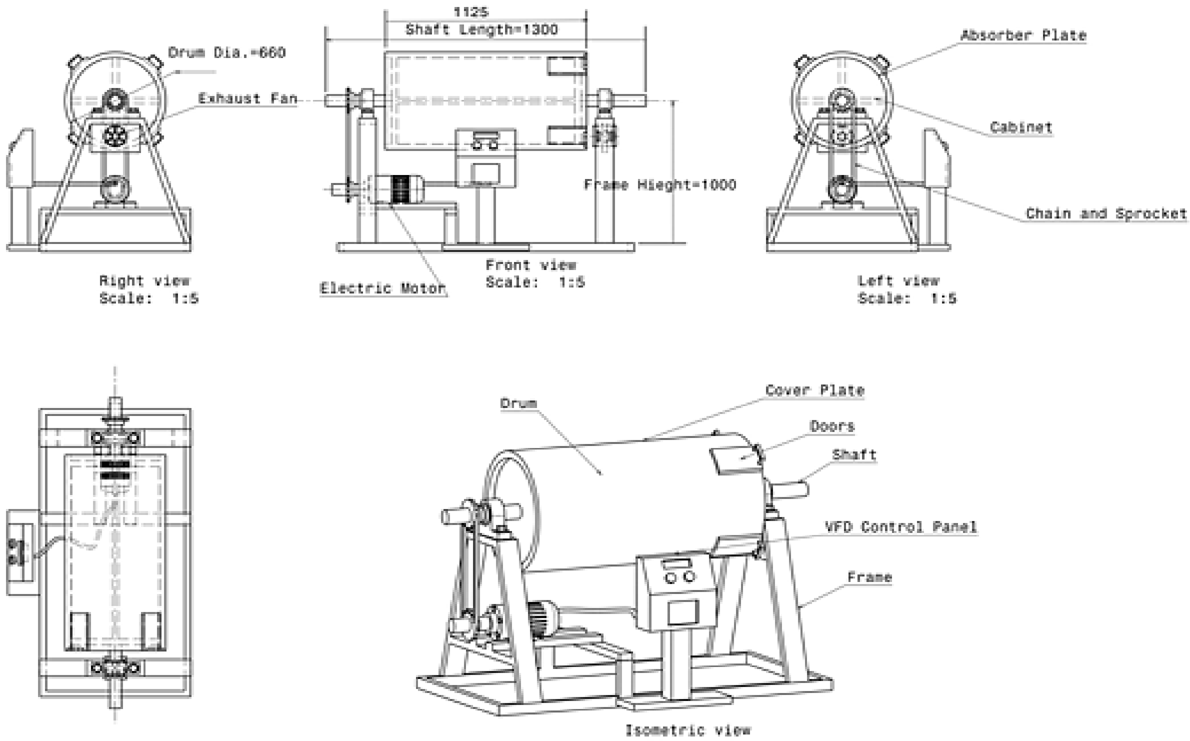


Figure 4.1. CATIA model of a conductive rotating drum type solar dryer



Detailed Isometric View Of Conductive Rotatung Drum Type Solar Grain Dryer

V. COMPONENTS AND WORKING OF CONDUCTIVE RORATING DRUM TYPE SOLAR DRYER

The objective of this research is to design a direct-type conductive rotating drum-type solar dryer in which the grains are dried simultaneously by both direct radiation through the transparent cover plate of the cabinet and by the heated absorber plate from the solar collector.

The materials used for the construction of the conductive rotating drum-type solar dryer are cheap and easily obtainable in the local market. Figures 6.1 and 6.2 show the main components of the dryer, consisting of the rotating drum solar collector, the drying cabinet, exhaust fan, induction motor with speed reduction gear box, variable frequency drive, etc.

Figure 5.1. Actual setup of conductive rotating drum type solar dryer

Working of conductive rotating drum type solar dryer:

A conductive rotating drum-type solar grain dryer is a system that utilizes solar energy to dry grains efficiently. The conductive rotating drum type solar grain dryer consists of a cylindrical drum made of a heat-absorbing material, such as stainless steel, painted in a special dark black color to maximize solar radiation absorption. The drum is mounted on a shaft, and the complete assembly of the dryer is mounted on a frame that allows it to rotate. Grains are loaded into the drum through an opening or doorway provided on the cover plate. The drum is designed to hold a specific volume of 128kg of grains while allowing proper airflow for drying. The rotating drum is placed in direct sunlight to absorb solar radiation. The dark color and heat- absorbing material of the drum help convert sunlight into heat energy.

The drum is rotated at a speed of 10 RPM using a motor and variable-frequency drive mechanism. The rotation helps to mix the grains continuously, ensuring even exposure to heat and airflow. As the drum rotates, the absorbed solar heat is transferred to the grains inside. The heated air circulates through the drum, carrying away moisture from the grains.

The rotation of the drum helps in achieving uniform drying by exposing all the grains to the heated air. Proper airflow is essential for effective drying. The design of the drum includes perforation holes on one of the ends of the drum that allow air to exit the drum. The heated air flows through the grains, removing moisture and carrying it out of the dryer. The moist air is typically vented out of the dryer using an exhaust system. The drying process continues until the desired moisture content is achieved in the grains. The drying time can vary depending on factors such as grain type, initial moisture content, solar radiation intensity, and dryer capacity. Once the grains have reached the desired moisture level, they are unloaded from the drum through an opening or doorway provided on the cover plate.

VI. EXPERIMENTAL PROCEDURE AND OBSERVATIONS

The tests were conducted between the periods of April and May of 2023. A preliminary test (or no-load test) was first conducted for two bright days to evaluate the thermal profile of the solar collector from 10:00 a.m. to 5:00 p.m. The atmospheric air temperature was noted and recorded by the use of a digital thermometer, as well as the corresponding drying cabinet inside temperature. At the start of the solar drying test, the fabricated solar dryer was positioned at a distance reasonable enough from trees and buildings in order to prevent the shading effect. Before conducting an experiment, the experimental setup was allowed to run for half an hour till the desired drying condition attained a steady state. Before the commencement of each solar drying test, the respective masses of the maize or green peas were recorded. Then the weighed and tagged grains were put into the drying cabinet, and the starting time was recorded. The temperature inside the solar collector drum cabinet and the atmospheric air temperature were measured with a digital thermometer.

At the end of each test, which lasted for 8 hours, the moisture content was calculated as a percentage of the final dried mass of the grains, and the difference between the initial mass of the grains and the hourly measured masses was used to calculate the percentage weight loss for each grain species. All the experiments were conducted at a rotary dryer speed of 10 rpm so that all the grain could be mixed and exposed uniformly to the drying air. To ensure reliability, conduct multiple experimental runs using different batches of grains and varying weather conditions.

6.1. Test conducted on Maize material

The drying of the maize in a rotating drum-type solar dryer was done in the month of April for two days. The drying time is a total of 8 hours for two days. The observation obtained for an hourly reading of 4 hours every day is tabulated in tables no. 6.1 and 6.2.

Observations on 15th April 2023 (Day 1).

5 kg of maize in a single cabinet of the drum,So the total weight of maize in the dryer was 20 kg.

Temperature of empty drum recorded = 72 ºC

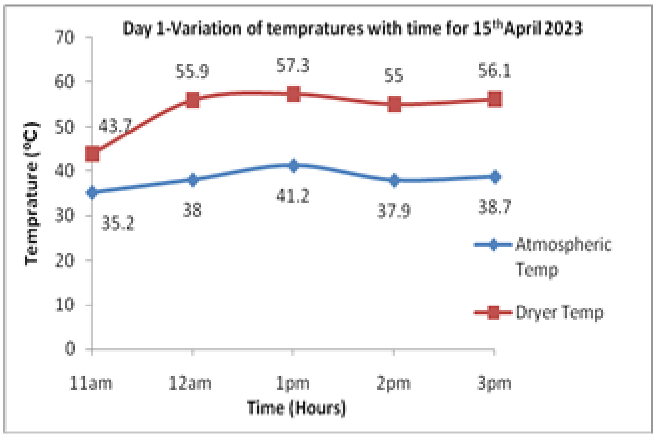
Motor running time = 4 hrs (2 hrs everyday)

Table No.6.1. Variation of temperature and weight with time on the first day

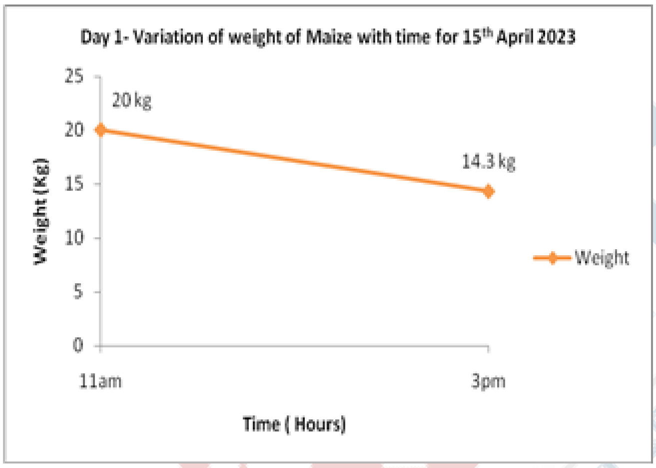
Day 1/ Time	11:00 am	12:00 am	01:00 pm	02:00 pm	03:00 pm
Weight of Maize (Kg)	20 Kg	---	---	----	14.3 Kg
Temp. inside the drum	43.7 ºC	55.9 ºC	57.3 ºC	55 ºC	56.1 ºC
Atmospheric Temp.	35.2 ºC	38 ºC	41.2 ºC	37.9 ºC	38.7 ºC

W_w - Weight of maize at 11:00 am= 20 Kg,
W_d - Weight of maize at 3:00pm = 14.3 Kg
W_w - Weight of grain on wet basis,
W_d - Weight of grain on dry basis
Weight reduction $= W_w - W_d = 20 - 14.3 = 5.7$ kg

The graphs are plotted between atmospheric temperature, temperature inside the drying cabinet, weight of maize, time of day, and data taken from the above tables. The graph shows the hourly variation of temperature and weight as the day progresses.



Graph No.6.1. Variation of temperatures with time for 15th April 2023 (Day 1)



Graph No.6.2. Variation of weight of Maize with time for 15th April 2023 (Day 1)

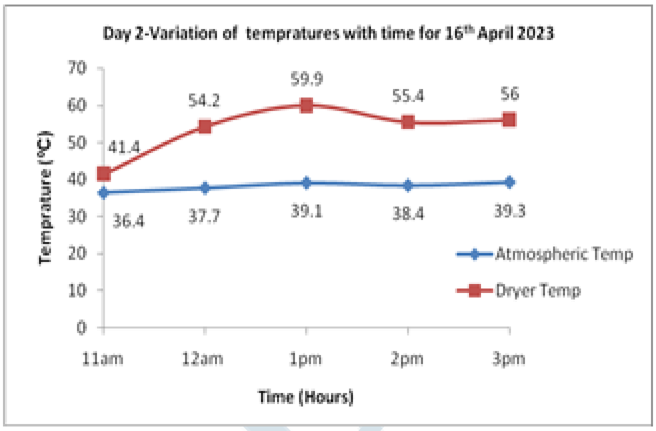
Observation on 16th April 2023 (Day 2).

Table No.6.2- Variation of temperature and weight with time on the Second day.

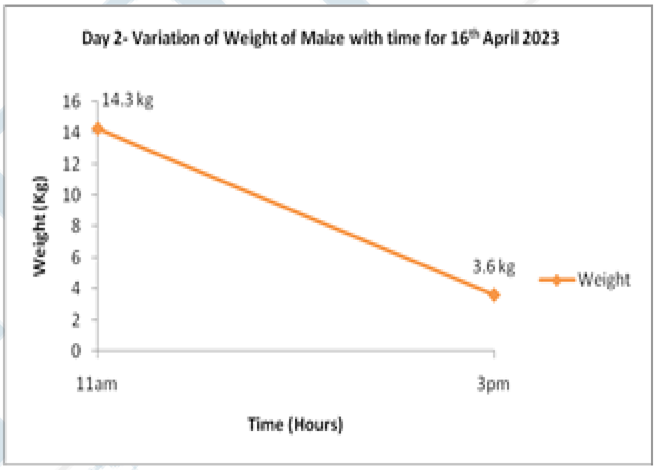
Day 2/ Time (hours)	11:00 am	12:00 am	01:00 pm	02:00 pm	03:00 pm
Weight of Maize (Kg)	14.3 Kg	---	---	---	3.6 Kg
Temp. inside the drum	44.1 ºC	54.2 ºC	56.9 ºC	54.5 ºC	56 ºC
Atmospheric Temp.	36.4 ºC	37.7ºC	39.1ºC	38.4 ºC	39.3 ºC

Weight reduction $= W_w - W_d = 14.3 - 3.6 = 10.7$ kg

The graph shows hourly variation of temperature and weight, as the day progresses.



Graph No.6.3. Variation of temperatures with time for 16th April 2023 (Day 2)



Graph No.6.4. Variation of weight of Maize with time for 16th April 2023 (Day 2)

6.2. Trial conducted on Green Peas material

Observations on 03rd May 2023 (Day 1).

5 kg of green peas in single cabinet of the drum, So total weight of green peas in dryer was 20 kg

Temperature of empty drum recorded = 70.3ºC

Motor running time = 4 hrs (2 hrs everyday)

Table No.6.3. Variation of temperature and weight with time on the first day.

Day 1/ Time	11:00 am	12:00 am	01:00 pm	02:00 pm	03:00 pm
Weight of Green Peas (Kg)	20 Kg	---	---	---	13.6Kg
Temp. inside the drum	42.9ºC	53.8ºC	55.4 ºC	54.9ºC	56.2ºC
Atmospheric Temp.	35.8 ºC	38.1ºC	39ºC	39.3 ºC	40.2 ºC

Weight reduction $= W_w - W_d = 20 - 13.6 = 6.4$ kg

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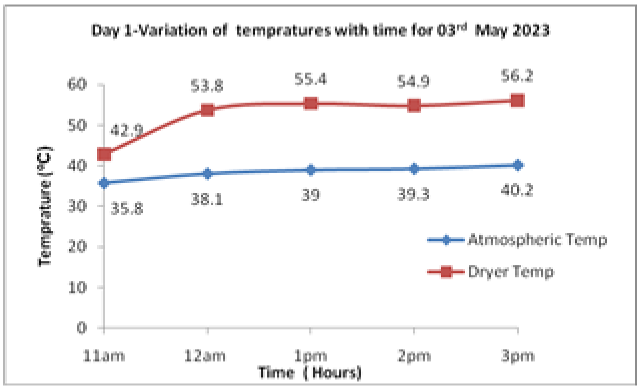
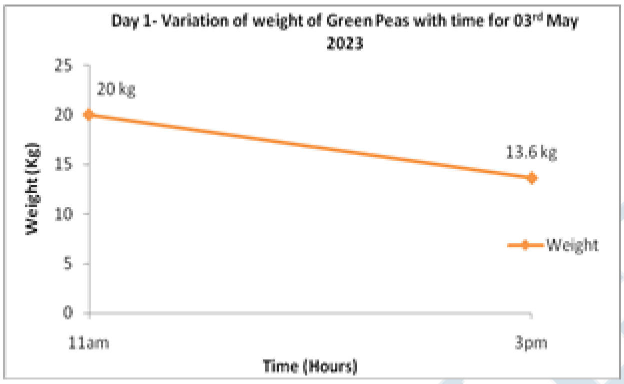


Graph No.6. 5. Variation of temperatures with time for 03rd May 2023 (Day 1)



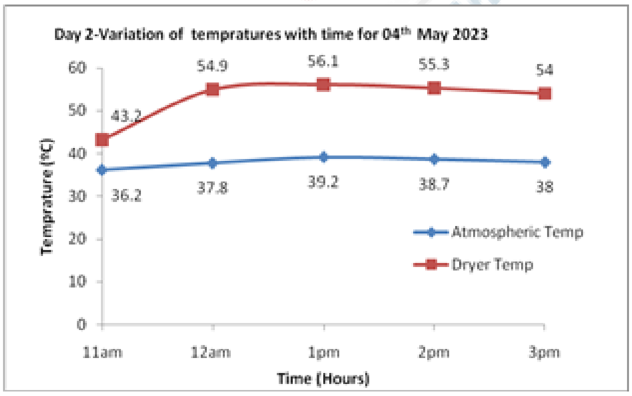
Graph No.6.6. Variation of weight of Green Peas with time for 03rd May 2023 (Day 1)

Observation on 04th May,2023 (Day 2).

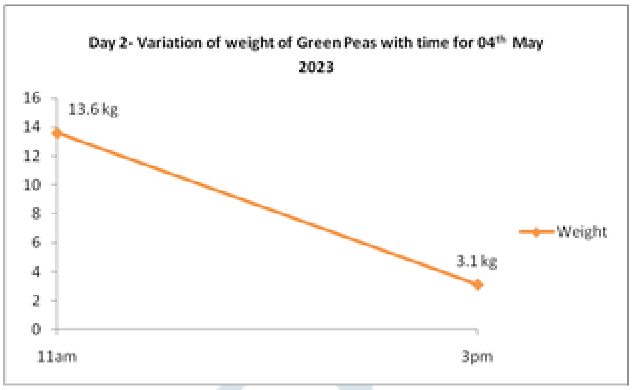
Table No.6.4. Variation of temperature and weight with time on the Second day.

Day 2/ Time	11:00 am	12:00 am	01:00 pm	02:00 pm	03:00 pm
Weight of Green Peas (Kg)	13.6Kg	---	---	---	3.1 Kg
Temp. inside the drum	43.2 °C	54.9°C	56.1°C	55.3°C	54°C
Atmospheric Temp.	36.2 °C	37.8°C	39.2 °C	38.7 °C	38°C

Weight reduction $=W_w - W_d = 13.6 - 3.1 = 10.5$kg



Graph No. 6.7. Variation of temperatures with time for 04th May 2023 (Day 2)



Graph No.6.8. Variation of weight of Green Peas with time for 04th May 2023 (Day 2)

VII. PERFORMANCE EVALUATION AND CALCULATIONS

The test procedure for both maize and green peas was the same. Sample results of drying maize and green peas were given in Table No. 7.1 and Table No.7.2

7.1. Dryer performance evaluated for 20 kg Maize grains

Table No. 9.1. Dryer performance evaluated for 20 kg Maize grains

Day / Time Slot	Time (Hours)	Atmospheric Temperature	Inside Dryer Temperature	Weight	Weight reduction
Day 1 11:00am - 03:00pm	1 hr	37.3 °C	55.1 °C	20 kg	6.2 kg
	2 hr	38°C	56.1 °C	---	
	3 hr	37.8 °C	56°C	---	
	4 hr	37.4 °C	54.4°C	13.8 Kg	
Day 2 11:00am - 03:00pm	5 hr	37.5°C	54.6°C	13.8 Kg	10.4 kg
	6 hr	39 °C	57 °C	---	
	7 hr	38.1 °C	55.1°C	---	
	8 hr	38.6 °C	55.3°C	3.4 Kg	

Average temperature inside the dryer =

$$\frac{46.1+55.1+56.1+56+54.4+45.3+54.6+57+55.1+55.3}{10} = 53.5\ ^{\circ}C$$

Average atmospheric temperature =

$$\frac{35.8+37.3+38+37.8+37.4+35.9+37.5+39.1+38.1+38.6}{10} = 37.6\ ^{\circ}C$$

The average temperature difference between atmospheric temperature and temperature inside the drum

= 53.4 - 38.2=15.2 °C

Moisture Content Removed:

$$\text{Moisture Content (\%)} = \frac{\text{Initial Weight} - \text{Final Weight}}{\text{Initial Weight}} \times 100\%$$

$$= \frac{20-3.4}{20} \times 100 = 83\ \%$$

The moisture content removed from the maize after drying is approximately 83 %.

Rate of drying:

Drying rate is well-defined as the quantity of moisture removed divided by time (Dhanushkodi et al., 2014).

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$$\text{Drying Rate} = \frac{W_i - W_d}{t} = \frac{20-3.4}{8} = 2.075 \text{ kg/hr}$$

Where, W_i= Initial weight of the sample, g or Kg
W_d = Weight after drying, g or Kg
t = Time of drying, hours

9.2. Dryer performance evaluated for 20 kg Green Peas grains

Table No.9.2 Dryer performance evaluated for 20 kg Green Peas grains

Day / Time Slot	Time (Hours)	Atmospheric Temperature	Inside Dryer Temperature	Weight	Weight reduction
Day 1 11:00am - 03:00pm	1 hr	38.1ºC	53.8ºC	20 Kg	6.4 kg
	2 hr	39ºC	55.4 ºC	---	
	3 hr	39.3 ºC	54.9ºC	---	
	4 hr	40.2 ºC	56.2ºC	13.6 Kg	
Day 2 11:00am - 03:00pm	5 hr	37.8ºC	54.9ºC	13.6 Kg	10.5 kg
	6 hr	39.2 ºC	56.1ºC	---	
	7 hr	38.7 ºC	55.3ºC	---	
	8 hr	38ºC	54ºC	3.1 Kg	

Average mean temperature inside the dryer =

$$\frac{42.9+53.8+55.4+54.9+56.2+43.2+54.9+56.1+55.3+54}{10} = 52.7\ ºC$$

Average atmospheric temperature =

$$\frac{35.8+38.1+39+39.3+40.2+36.2+37.8+39.2+38.7+38}{10} = 38.2\ ºC$$

Average temperature difference = 52.7-38.2=14.5 ºC

Moisture Content Removed:

$$\text{Moisture Content (\%)} = \frac{\text{Initial Weight} - \text{Final Weight}}{\text{Initial Weight}} \times 100\ \%$$

$$= \frac{20-3.1}{20} \times 100 = 84.50\ \%$$

The moisture content removed from the maize after drying is approximately 85 %.

Rate of drying:

Drying rate is well-defined as the quantity of moisture removed divided by time (Dhanushkodi et al., 2014).

$$\text{Drying Rate} = \frac{W_i - W_d}{t} == \frac{20-3.1}{8} = 2.12 \text{ kg/hr}$$

Where, W_i= Initial weight of the sample, g or Kg
W_d= Weight after drying, g or Kg
t = Time of drying, hours

VIII. RESULT AND DISCUSSION

After completing all the procedures and methods of dryer construction, the performance of the dryer was tested by conducting different trials. A drying test was conducted to check the performance of the dryer by using freshly harvested maize and green peas grains. The grains were evenly spread on the absorber plate to ensure uniform drying of the product. Equal weights of the sample were loaded into each drying cabinet.

Table No. 8.1 Performance evaluated for the maize and green peas.

Parameters	Maize	Green Peas
Weight before drying	20 Kg	20 Kg
Weight after drying	3.4 kg	3.1 Kg
Drying Time in Dryer (Hrs)	8 hrs	8 hrs
Outside Drying Time (Open Sun Drying Approximately)	4 – 7 days	2-4 Days
Temperature range inside the cabinet of dryer	46.1–59.9 ºC	42.4 - 56.2 ºC
Average atmospheric temperature	37.6 ºC	38.2 ºC
Average temperature inside the cabinet of dryer	53.5 ºC	52.7 ºC
Drying rate	2.075 kg/hr	2.12 kg/hr
Percentage of moisture removed	83 %	85 %

Maize Samples -

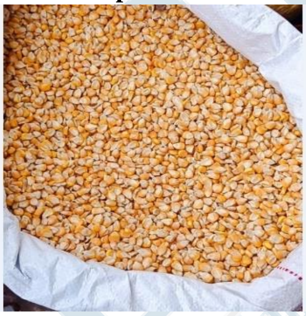
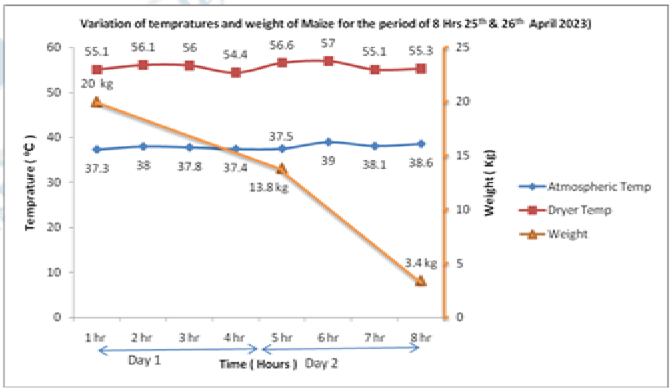


Figure. 8.1. Maize before drying

Figure. 8.2. Maize after drying



Graph No.8.1. -Variation of temperatures and weight of Maize for the period of 8 Hrs with time for 25th & 26th April 2023

Green Peas sample -

Figure.8.3. Green Peas before Drying

Figure. 8.4. Green Peas after Drying

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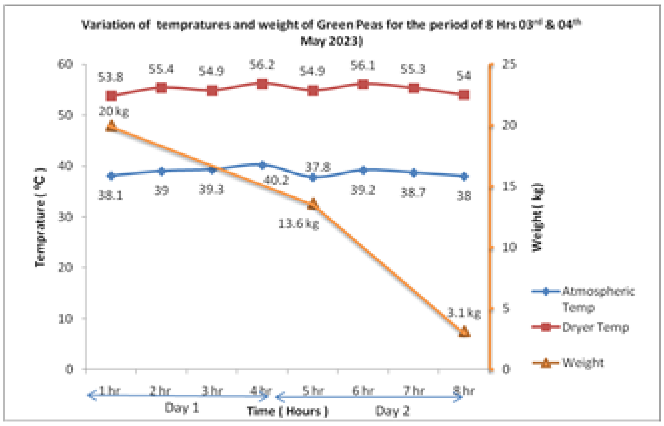

Graph No. 8.2. Variation of temperatures and weight of Green Peas for the period of 8 Hrs with time for 03rd & 04th May 2023

8.1. Temperature and weight:

The graphs No. 8.1 and 8.2 show the temperature variation at different stages of the dryer during the testing hours from 11:00 a.m. to 3:00 p.m. on each day of the test. The dark red line indicates the inside temperature of the drum cabinet, and the dark blue line indicates the atmospheric temperature. The weight reduction of grains is also indicated by the dark orange color line.

The average drying air temperature recorded inside the drying cabinet of the dryer was about 53.4°C. The maximum drying air temperature recorded was about 59.9°C during peak sunshine hours, and the minimum temperature recorded was about 41.1°C during the starting hours of drying the grains. Assume that the average maximum solar intensity received in India is 5 KWhr/m². Average atmospheric temperatures recorded were 38.2°C in the months of April and May. The temperature inside the cabinet of the dryer was higher than the ambient temperature. The average temperature difference between the atmospheric temperature and the temperature inside the drum cabinet was 15.2°C. The total heat energy to be generated inside the proposed drying installation amounts to 7.42 KWhr per day for a window period of 8 hours, or 0.231 KW per hour.

8.2. Moister removal

The dark orange line indicates the weight reduction of grains as time progresses. The graph would show a declining line, indicating that as the moisture content was removed and the grains dried, the moisture content decreased. The average moisture content was reduced by about 83% from maize and 85% from green peas for the given sample materials. Moisture removal on the first day of the test was observed due to the evaporation of free moisture migration from the outer surface layers, and then increased on the second day of the test due to the internal migration of moisture from the inner layers to the surface of the grains. Higher moisture reduction during the second day due to the internal migration of moisture from the inner layers of the grains. This results in a process of uniform dehydration of wet grains due to tumbling action and evenly mixing of grains in a drum rotating at a constant speed of 10 rpm.

8.3. Drying rate:

The initial weight of maize (20 kg) was selected as a sample of the grains to check the drying rate. When the time passed, the grains were taken out of the drying cabinet and re-weighted. The loss in weight was recorded, and then using the initial and final weights of the grains, the drying rate was calculated. During the first day after 4 hours, the drying rate of maize was 1.6 kg/hr, and on the second day after 4 hours, the drying rate was 2.55 kg/hr. On the second day of the trial, the drying rate increased due to the greater weight reduction of the grains. The average drying rate was also calculated as the drying process was completed after 8 hours, and the drying rate was 2.075 kg/hr. The same situation was observed while calculating the average drying rate of green peas. The drying rate was 1.6 kg/hr on the first day and 2.62 kg/hr on the second day of the trial. The average drying rate was 2.12 kg/hr of green peas.

8.4. Comparison of drying techniques and quality of grains:

The reduction in weight of maize from 20kg to 11.2kg after 14 hours at the end of 2 days under direct open-sun drying was taken into consideration for comparison between open-sun drying and solar drying. The drying rate was found to be very slow as compared to solar dryers due to lower heat and mass transfer coefficients. The average drying rate of maize was 0.6 kg/hr, which often took more time than solar drying. Poor-quality maize was obtained in sun drying mainly due to its exposure to the open atmosphere, exposing it to dust, birds, insects, rodents, etc., which may induce the formation of microbiological substances in maize. A conductive rotating drum-type solar dryer is more suitable than open-sun drying for producing high-quality maize for small holders.

Open-sun drying is highly dependent on weather conditions, making it unreliable during cloudy, rainy, and humid days. In contrast, rotating drum-type solar dryers can function more consistently as they can utilize solar energy even on partly cloudy days. It requires a large space to spread out the grains in a single layer. Rotating the solar dryer compactly didn’t require more space and also provided better protection from contaminants and pests. To ensure proper drying, it requires constant monitoring, including turning the grains to ensure even drying. This can be labor-intensive and time-consuming, whereas a rotating solar dryer is automated and requires fewer manual labor operations. Solar drying generally preserves the natural color of grains better than open-sun drying, which can lead to discoloration due to prolonged exposure to sunlight. Solar drying at moderate temperatures helps to retain the nutritional content and texture of grains, such as vitamins and minerals, better than high-temperature drying methods like conventional ovens, heat pumps, or mechanical dryers.

IX. CONCLUSION

A conductive rotating drum-type solar grain dryer has been designed and constructed. The system was tested using freshly harvested grains of Maize and green peas. The solar dryer could serve as a prototype model of a commercial grain dryer used in the agricultural field and grain drying and food processing industries, and it could also be employed as laboratory demonstration equipment in an engineering workshop. However, results obtained show that, under favorable weather conditions, it was possible to dry 128 kg grains effectively using conductive rotating.

The average drying temperature recorded inside the drying cabinet of the dryer was about 53.4°C. The average temperature difference between the atmospheric temperature and the temperature inside the drum cabinet was 15.2 ºC, which was sufficient for drying maize and green peas grain effectively for good grain quality. The total heat energy to be generated inside the proposed drying installation amounts to 7.42 KWhr per day with a drying rate of 2.075 kg/hr with moisture removed 83% from maize grains and 2.12 kg/hr with moisture removed 85% from green peas, respectively, which demonstrates its functionality. For the required levels of heat needed to dry grain, the present study shows that even inexpensive solar drying units can be quite efficient. The proposed design reaches an amount of 35000/- Rs, representing the minimum price for similar facilities in the market for the drying application.

Conductive rotating drum-type solar grain dryers are effective in drying a variety of grains, including maize and green peas. They offer an efficient and cost-effective method for small- to medium-scale farmers to dry their produce. These dryers help preserve the quality of grains by providing uniform drying conditions. This can result in higher market prices for dried products and reduced waste.

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